LIVESTOCK AND LAND-USE SURVEYS IN SUB-SAHARAN AFRICA

William Wint and David Bourn

Oxfam Research Paper 11

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Environmental Research Group Oxford (ERGO)

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Oxfam Research Papers report the findings of original research, commissioned by Oxfam (UK and Ireland) to support its overseas programme of relief and development.

Oxfam (UK and Ireland)

A catalogue record for this book is available from the British Library.
ISBN 0 85598 284 5

Published by Oxfam (UK and Ireland)
274 Banbury Road, Oxford, OX2 7DZ

Typeset in 11 pt. New Century Schoolbook
Printed by Oxfam Print Unit
Oxfam is a registered charity no. 202918

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Acknowledgements

This report draws on data collected in the field over the last 13 years. The authors gratefully acknowledge the efforts and assistance provided by all the local and expatriate staff concerned, as well as the staff of the numerous national and international institutions that have supported, commissioned or funded the surveys, with particular thanks to the International Livestock Centre for Africa, under whose aegis many of the techniques used were developed and tested. The authors wish to thank the people who read and commented on various drafts of the report, including John Rowley of Oxfam; David Rogers, Mike Packer, Simon Hay, Malcolm Coe and Clive Hambler of the Department of Zoology, Oxford University; Brian Williams of the London School of Hygiene and Tropical Medicine; Richard Baker of the UK Central Science Laboratory, Harpenden; and Camilla Toulmin and Iain Scoones of the International Institute for Environment and Development, London.

This paper was written for Oxfam by William Wint and David Bourn of the Environmental Research Group, Oxford. It has been edited and prepared for publication by Olivia Graham.

Introduction

For many years now, it has been apparent that the extensive savannah regions of Africa are in a state of transition. They are no longer 'natural' ecosystems, but are subject to increasing pressures on land use, as a result of the conflicting interests of farmers, pastoralists, foresters, and conservationists. A major debate is taking place on how these areas can be developed sustainably, and how an appropriate balance between crops, livestock, trees, and wildlife can be established and maintained.

In recent years there has been an increasing awareness that arid rangelands have been progressively degraded by drought and over-exploitation. Until recently, the focus of this awareness has been on the advance of the desert into degraded areas. Toulmin (1993) has noted that the terms of the land degradation debate have changed over the past few years from 'combating desertification' to 'improving natural-resource management in dry land regions'. In her view this is more than just a change in terminology. It has helped to shift attention to the institutions responsible at local and national levels for managing the ways in which natural resources are actually used.

This is a sensible approach, but at the same time it must be recognised that sound management depends on reliable information, and that not enough is known about either the current state of natural resources in many sub-Saharan countries, or how the situation has changed over time. Without more and better information, it is far from certain that any strategies designed to improve matters will succeed. With the growth of human populations there has been an expansion of agriculture and a transformation of vegetation and land use, which have not been adequately monitored and which are poorly documented.

This paper presents the findings of a preliminary analysis of data from systematic low-level aerial surveys and complementary ground studies of livestock and land use in Mali, Niger, Nigeria, Sudan and Chad. The total area covered was more than 1.5 million square kilometres. The surveys were carried out between 1980 and 1993, in both wet and dry seasons. The analysis of the data provides an independent and objective assessment of resources across a range of agro-climatic zones. The paper identifies some fascinating and significant environmental correlates of livestock distribution, and highlights features worthy of further investigation.

What determines livestock numbers?

This is not a straightforward question, and different researchers have come to both complementary and divergent views on it. In a regional study of wildlife and pastoral systems in Eastern and Southern Africa, Coe et al. (1976) found strong correlations between animal numbers, mean annual rainfall, and above-ground primary production.

They noted that there were more animals in six pastoral areas of Kenya surveyed by Watson (1972) than in other areas with equivalent rainfall. Many domestic animals had died in the six areas during the 1973/74 drought, and this was interpreted as an indication that the previous stocking levels had been above the long-term carrying capacity.

Whilst acknowledging that other factors, such as soil fertility and ground water availability, also influence primary production, and hence carrying capacity at the local level, Coe et al. (1976) argued that rainfall was the main determinant of animal numbers across a broad range of savannah regions receiving 160-700mm precipitation per annum. The underlying thrust of their argument was that wildlife systems, having evolved over millions of years, provide as good an indication as any of how many animals might be sustainably supported in the medium to long term.

Extending this approach to tsetse-free zones of Ethiopia, Bourn (1976) showed that cattle numbers increase with:

human population density;
rainfall;
altitude.

Tsetse-infested areas of Ethiopia generally support much lower cattle densities than those which are tsetse-free. This pattern is repeated across the continent. In tsetse-free countries national cattle numbers increase with mean annual rainfall; there are substantially fewer animals in tsetse-infested countries; and countries with significant numbers of trypano-tolerant cattle have intermediate numbers of animals.

Building on these findings and incorporating additional sources of information, Bell (1982 and 1985) drew attention to the important modifying influence of soil-nutrient status on the general relationship between plants and animal populations and water availability.

In a regional assessment of South American rangelands in Argentina and Uruguay, Oesterheld et al., (1992) found that domestic ungulate numbers for a given level of above-ground primary production (which can be equated with rainfall) were greater than those of wild herbivores in natural ecosystems world-wide, and concluded that 'elementary' (by which they meant extensive) animal husbandry practices raise the carrying capacity of rangelands for large stock.

However, this conclusion has been disputed by Fritz and Duncan (1993), who were unable to find any significant difference between pastoral grazing areas and natural wildlife sites, for example game reserves, in savannah regions of Africa. Instead, their analysis, similar to that of Bell, showed that, for any given rainfall level, soil type and nutrient status (presumably reflecting the quality of available grazing) were the key determinants of animal numbers in both pastoral and wildlife systems.

Unreliable statistics?

Can we rely on national livestock population figures? These are derived from various sources of information, including vaccination and dip-tank records, agricultural field surveys, tax returns, and slaughter, marketing, and trade data.

Where countries have undertaken major vaccination campaigns, against rinderpest for example, this obviously gives an indication of animal population size, but only rarely are all animals vaccinated, and an assumption must therefore be made about the proportion which were not treated. Also, there is always the possibility that some animals were vaccinated more than once. Major disease-control campaigns are targeted at single species, usually cattle or small ruminants. Other species of livestock are rarely included, and estimates of their population size tend to be most uncertain.

No standard method of assessment exists and methods vary from country to country. The reliability of livestock population figures obviously depends on the quality of the data collected and the validity of underlying assumptions. FAO publishes an annual compilation of national livestock statistics derived from information provided by member states, but these figures are rarely based on objective field surveys and are not necessarily reliable.

Carrying capacity

In recent years, there has also been a great deal of thinking about the following questions:

1 Is it possible to calculate or define a maximum livestock density (often known as 'carrying capacity') that an area can permanently support?

2 Is the idea of a fixed carrying capacity applicable to pastoral (or agropastoral) systems where livestock management is dominated by risk-aversion strategies?

3 What exactly is meant by the term 'desertification', which is so commonly used in the literature and is increasingly a focus of development policy?

In recent years the usefulness of the concept of carrying capacity has been called into question by many writers. Behnke et al., (1993) suggest that whilst it may be theoretically possible to define a maximum sustainable stocking level for an area of land as a preliminary indicator of potential overstocking, the idea of carrying capacity is largely irrelevant to the formulation of livestock policy. This is partly because it is not possible to regulate animal numbers effectively given current systems of communal land-tenure and opportunistic pastoral management in Africa.

Others argue that the idea of a fixed and constant sustainable stocking level is fundamentally flawed when applied to pastoral systems. This is because there is too much annual variation in productivity of any one area, and because livestock are not generally kept in one place for the whole year round. In particular, there is a need to establish new ways of predicting natural variability and the ways in which pastoral management adapts to it, and also to develop more appropriate techniques for assessing rangeland carrying capacity.

So, conventional theories and recommended management practices derived from the idea of carrying capacity are increasingly thought to be inappropriate for Africa.

A unique data set: the ERGO database

The rest of this paper concentrates on the somewhat surprising findings of a preliminary analysis of a database assembled by The Environmental Research Group animals were vaccinated more than once. Major disease-control campaigns are targeted at single species, usually cattle or small ruminants. Other species of livestock are rarely included, and estimates of their population size tend to be most uncertain.

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A unique data set: the ERGO database

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Oxford (ERGO). The database is derived from standardised methods of information collection over a wide variety of environments across Africa, from the arid rangelands of the Sahel to the humid forest zone.

The database consolidates the records of a series of systematic low-level aerial surveys and complementary ground studies conducted in Mali, Niger, Nigeria, Sudan and Chad since 1980. These surveys were carried out by three groups: ERGO, the International Livestock Centre for Africa (ILCA), and Resource Inventory and Management (RIM).

The surveys cover a total area of more than 1.5 million square kilometres, most of which was surveyed in both wet and dry seasons. Some 13,000 geographically co-ordinated sample points are included within the database. Survey records of livestock, human settlement, vegetation and land use are associated with each sample point. Other attributes include mean annual rainfall, agro-climatic zone and the presence or absence of tsetse.

Data collection, coverage and contents

The analysis is based on information from three primary sources:

* **standard cartography,** for mean annual rainfall, plant growing period, soils, and tsetse, used to stratify the survey information;

* **systematic low-level aerial surveys,** for the direct observation of pastoral livestock, human settlement (roof tops), vegetation and land use;

* **complementary ground surveys,** for information about village livestock composition and local production systems.

Low-level aerial surveys
Aerial surveys are normally conducted from a height of between 400 and 2,000 feet above the ground. They are designed to collect numerical information about target populations and distributions over large, often remote, areas within a short period of time. The survey technique is usually based on a systematic flight pattern which provides uniform coverage of an entire region and enables a geographically co-ordinated gridded database to be established. Sample counts are taken from each grid cell. Key features of this technique are its repeatability, and that it does not rely on any previous knowledge of the area concerned. Repeat surveys at critical times of the year allow seasonal changes in distribution and abundance to be determined. For more detailed information about the aerial survey techniques used, see Appendix 1.

Ground surveys
The ground surveys which were used were designed to collect information which cannot be obtained from aerial reconnaissance, (such as the number of animals kept under shelter) and to provide data which can be combined with aerial counts to give estimates of variables that neither technique can address on its own. An example is the number of poultry kept in rural villages: air counts give the number of habitations in a sample grid; ground counts provide the number of birds per habitation. Combining the two figures gives village poultry population estimates and

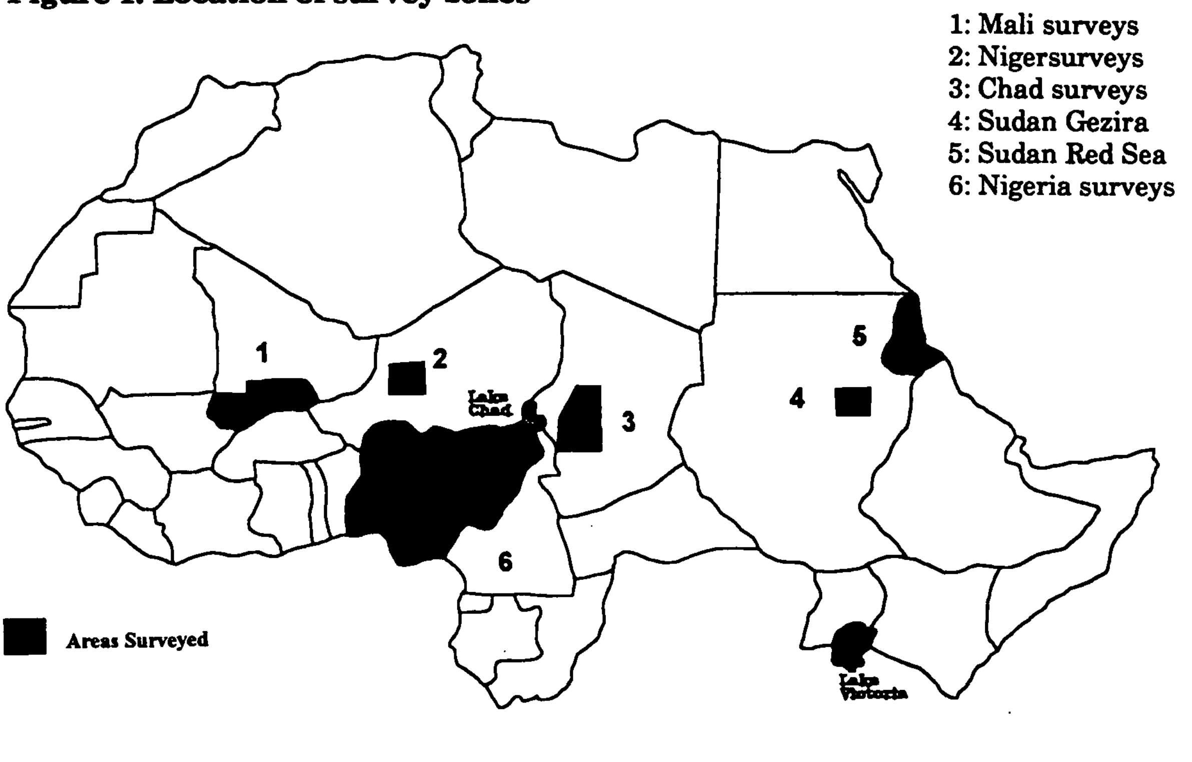
distributions.
Ground surveys can also be used to differentiate between the large ruminants that are kept in association with human settlement, and those that are found away from villages. This distinction can be made in one of two ways. Either the aerial survey observers make a separate record of animals seen within village boundaries, or they exclude such livestock from the aerial counts altogether. If the second course is adopted, then the estimates of total livestock numbers are calculated by adding the numbers derived from aerial counts to those derived from the ground survey and aerial habitation records.

This integrated air/ground approach provides an objective basis for resource assessment and a good understanding of local production systems. Since 1986, all surveys carried out have included a ground element.

Sites surveyed and data collected

The locations of the surveys carried out are shown in Figure 1 below. Details of the date, area and funding agency for each survey, together with a summary of the categories of information collected are found Appendix 2.

Figure 1: Location of survey zones



Livestock
All surveys included in the ERGO data set counted cattle, camels and small ruminants visible from the air. From 1986 onwards, village animals were also counted by complementary ground surveys (see above).

Habitation
Rural village and pastoralist (i.e. permanent and temporary) habitation can be easily assessed and differentiated from the air. In the majority of surveys, each of these two categories were broken down into a number of structural types which may reflect the ethnicity of their builders: for example the Fulani rugas of West Africa, the Beja tents of Sudan, or the Tiv huts of Nigeria. For the purposes of this analysis, however, only village habitation has been included in the dataset. This is because it has been assumed that the pastoralist habitation will always be found where the pastoral livestock are, and therefore will not shed any light on the relationship between human habitation and livestock numbers.

Village dwellings are considered to represent either agropastoralists, arable farmers, or the inhabitants of village and towns. Dwellings in larger towns and cities (more than 5,000 dwellings or covering an area of more than 10 square kilometres) have also been excluded from the present data.

Vegetation and land use
Land use estimations in different surveys are less directly consistent than the other assessments. In the earlier studies, relatively few categories were considered — generally cultivation and some measure of grazing. The later surveys recorded vegetation categories that can be amalgamated into seven basic types: land within the cultivation cycle (active cropping plus fallow), bare ground, grassland, scrub, open woodland, dense woodland, and forest. In a number of surveys grass cover was also assessed. This differs from grassland in that the scrub and woodland categories, as well as grassland, support grass. Where grass cover was not measured specifically, an index has been calculated and tested in areas where grass cover was specifically assessed in order to confirm its relevance and accuracy.

Accuracy of the data — are they reliable?

Though the vegetation type was usually assessed visually, rather than photographically, comparisons of vegetation types which are constant from season to season were assessed consistently in repeat surveys, suggesting that the method yields accurate results. For example, in the Bahr el Ghazal Region of Chad, woody vegetation was assessed in 1991 at 14.3 per cent and in 1993 at 13.6 per cent. In Gongola State, Nigeria, grassland was estimated in 1983 and 1984 at 14 per cent and 17 per cent respectively, and in Niger State, Nigeria, cultivation was estimated in 1989 and 1990 as 20 and 21 per cent respectively. These comparisons provide reasonable grounds for assuming that vegetation and land-use data are sufficiently precise to be meaningful.

Livestock and habitation estimates are also made visually, but corrected for observer error by comparing visual estimates with counts from photographs. A 'bias' is then calculated, and the correction factor applied to all observer counts over 10. Calculated observer biases are usually less than 5 per cent, and commonly between 1 per cent and 2 per cent. Repeat surveys of permanent habitation types, which should not change much from year to year, show surprisingly little variation. For example, in the Bahr el Ghazal region in Chad the 1991 and 1993 estimates for permanent habitations were 79,700 and 82,800 respectively, and for Niger State, Nigeria for 1989 and 1990 were 17.5 and 17.8 per square kilometre respectively.

Data processing and analysis

As can be seen from the table of surveys in Appendix 2, a number of areas were surveyed during both dry and wet seasons, and some were surveyed during a particular season in more than one year. When examining information from several sites and times, two distinct analytical approaches are possible. One can either look at each individual survey dataset, draw conclusions for each one, and then build a more general picture; or one can try first to establish a general picture, and then investigate the degree to which the results from specific areas confirm the overall patterns.

It is the second approach which has been used here. This is based on the assumption that any relationships which are strong enough be statistically significant across the wide range of land types and ecological conditions that have been surveyed are of fundamental importance to livestock management. For this preliminary analysis, data from duplicate surveys have been averaged to give a single figure for each variable for each grid. This intentionally smooths out any seasonal or annual variation, so as to provide an initial overview of the data. In due course, it is planned that the data be disaggregated, and the effects of seasonal factors investigated.

Similarly, it was decided that this preliminary analysis should look at livestock as a single variable, rather than treat individual species separately. This is done by converting all species of livestock into Tropical Livestock Units (TLU): one TLU is equivalent to one camel, 1.43 cattle, two equines, or ten small ruminants. This approach has two main advantages. First, the results from areas with different species compositions can be compared directly; second, these results can then be related to carrying capacities (expressed in kilograms per square kilometre) worked out for different ecosystems — particularly those where wild animals form a substantial element of the grazing herbivore biomass.

It should be emphasised that both wild animals and horses and donkeys have been excluded from these analyses. Wild animals were counted in all the surveys carried out, but were so infrequently recorded as to be insignificant. Equine numbers were recorded only in the later surveys, and so their exclusion allows data from the earlier surveys to be included in the analyses. (Even where equines are common they represent only a small fraction of the total livestock numbers.)

Preliminary findings

Relationships between livestock and environment

The correlations between livestock density and different environmental factors show some interesting, and rather startling relationships. For those who are interested in the statistical mechanics, Appendix 3 provides a description of the terms and procedures and a worked example. Appendix 4 gives the graphical representation of each relationship noted below, with degrees of variation being indicated by the bars. The important thing for non-statisticians to retain is that throughout the analysis, and for each of the relationships examined, there is considerably less than a one in ten thousand chance that they are false.

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The first and strongest association shown by the data indicates that livestock aggregate in the greatest numbers where there is most cultivated land. Not only is there an even rise in livestock density with cultivation levels, but the degree of variation is quite low, and the statistical levels of significance are astonishingly high.

Not surprisingly, the relationship between animal numbers and the density of permanent human settlement (the number of rooftops per square kilometre) is also very strong, although, interestingly, it is slightly weaker than the association with cropping levels, and the variation, particularly for the more intensely cropped categories, is a little greater.

Animals numbers are also strongly correlated with rainfall, though not in a straightforward linear fashion as are the previous two relationships. The driest areas (with between 37.5 and 250mm precipitation per year) support very low livestock levels — an average of 1.28 TLU (320kg) per square kilometre. However, a modest increase in rainfall (between 250mm and 500mm precipitation per year) is associated with a fourteen-fold rise in livestock levels to 18.29 TLU (approximately 4600kg) per square kilometre. Livestock levels reach a peak of 21 TLU per square kilometre at around 825mm, and then drop fairly evenly as it gets wetter.

It is not only received wisdom, but intuitively reasonable, that domestic livestock should be concentrated where there is an abundance of natural grazing. But, not only do the data not support this hypothesis, they actively suggest that higher livestock densities are found in areas with less rangeland. However, although this relationship is significant, it is weak, and a possible explanation is that livestock numbers are so variable at specific levels of rangeland that no real trend can be reliably discerned.

However, total livestock units do rise consistently with the levels of grass cover within all natural vegetation categories. More animals are found in areas with more grass. But there is a lot of variation, particularly at the higher levels of grass cover, and accordingly, the relationship is comparatively weak compared to the relationship between livestock and cultivation. Variation in levels of grass cover explains only 10 per cent of the variation in livestock density, as compared with the 50 per cent explained by either cultivation or habitation levels.

Given that 'total livestock units' incorporates both those animals that are managed pastorally, and those that are closely associated with human settlement, perhaps it is to be expected that the primary determinants of livestock distribution are those most closely linked to human activity — namely cultivation and settlement levels. If the traditionally held views are correct, and animals go to where there is grazing, examining these same relationships for the more pastorally managed livestock should reveal weaker relationships between animal distribution patterns and human activity.

This is indeed the case. Both cultivation and habitation levels are less closely correlated with pastoral livestock units than with total livestock units. Nevertheless, the relationship between pastoral animals and cultivation levels is still substantially the strongest of those examined. As with total livestock units, pastoral livestock units rise with cropping intensity, though the increase levels off if more than half the land area is cultivated.

However, the link between pastoral animal distribution and permanent human habitation levels appears to be more complex. Pastoral animal numbers rise to a maximum at habitation densities of around 20 rooftops per square kilometre, then fall again in the more populous areas. Accordingly, despite its statistical significance, this relationship is sufficiently weak to be of little help in predicting pastoral livestock abundance.

The natural environmental factors most closely related to pastoral animal numbers are annual rainfall and percentage grass cover. Pastoral animal numbers rise to a maximum at rainfall levels of around 825mm, and then decline to zero at about 2500mm. This pattern is similar to that described for total animal numbers, except that pastoral livestock appear to be absent from the very wettest areas, presumably because of the threat of vector-borne and other diseases.

The distributions of rangeland and pastoral animal numbers are not significantly correlated. Given the significant, if weak, relationship between rangeland and total animal numbers, this result is perhaps somewhat unexpected as it would seem justifiable to assume that pastoral animals are more closely linked to rangeland than are village livestock. The lack of association between pastoral animal distributions and rangeland suggests that the association between total animal numbers and rangeland should be viewed with some reservation.

The presence of grass in all natural vegetation categories, as represented by grass cover, is, however, positively correlated to pastoral animal numbers. Where there is more grass, there are more pastoral animals, though an increase above 50 per cent grass cover appears not to be accompanied by a similar increase in animal densities. Statistically, the relationship is weak, especially when compared to that with cultivation, primarily because there is a lot of variability in animal densities at both high and low levels of grass cover.

It is clear from the results presented above that the distributions of total animal numbers and of pastoral animals are linked in very similar ways to the extent of human activity and the abundance of natural grazing. Both livestock categories are closely linked to cultivation rather than natural grazing.

Summary of preliminary findings:

Relationship (all livestock)	Strength of relationship	Comments
1 Livestock aggregate in greatest numbers where there is most cultivated land.	Very strong.	
2 Livestock aggregate where there is permanent human settlement.	Not as strong as (1) and greater variability where land is more intensely cropped.	
3 Animal numbers correlate with rainfall.	Not a linear relationship: numbers peak at 825mm.	
4 Fewer livestock are found in areas with more rangeland. variable that no	Significant but very weak.	Possible that numbers are so reliable trend can be found.
5 More animals are found in areas with more grass cover.	Significant, but much less so than (1) and (2).	N.B. This category is total grass cover and includes areas of woodland, scrub etc.
Relationship (pastoral livestock only)		
6 Pastoral livestock numbers rise with cropping intensity but level off once more than half the land is cultivated.	Very strong.	
7 Pastoral livestock numbers rise to a maximum at 20 rooftops per sq.km., and fall as area becomes more populous.	Significant, but rather weak.	
8 Distributions of rangeland and pastoral animals not significantly correlated.		Unexpected. Suggests that association between total livestock units and rangeland [see (4) above] should be viewed with reservation.
9 Pastoral livestock numbers positively correlated to grass cover (presence of grass in all natural vegetation categories); above 50% grass cover, no further increase in livestock numbers.	Much weaker relationship than that with cultivation.	

However, it is possible that the apparent relationships are camouflaging unknown interactions and associations between the different variables included in the analysis. For example, it may be the case that both cultivation and grazing availability are actually determined by rainfall, and that the apparent relationships between human activity and livestock levels are merely a by-product of a stronger cause and effect link between livestock and rainfall.

This problem can be addressed by multiple stepwise regression analyses, which prioritise the correlations, and then compensate for hitherto unseen interrelationships between the predictor variables. An illustrative example is described in Appendix 5.

The results are shown below in Table 1. These strongly confirm the assertions put forward above that human activity, in the form of either cultivation or settlement density, is consistently the most important predictor of both total and pastoral livestock distributions. Second most important is rainfall. Measures of natural grazing, either rangeland or grass cover, contribute little to the explanation of animal numbers.

Table 1: Multiple regressions of livestock biomass with environmental variables

(Figures in Brackets are % variance explained at each step of the regression)

Dependent Variable	Best predictor	2nd predictor	3rd predictor	4th predictor	Other Significant Correlates
Mean Total TLU R^2=.7112: DF=8,3264	+.3600Hab (60)	+.2997Rain (+2%)	+.2466Cul (+2%)	+.1536GrCov (+2%)	–Open, +GrLand, +FoWd, –Dense
Mean Pastoral TLU R^2= 0.4585: DF= 6,4029	+.3516Cul (34)	+.4873Rain (+8%)	+.1396GrLand (+3%)	+.1189GrCov (+1%)	–Open, +FoWd
Proportion Pastoral R^2 = .3090: DF = 7,2545	–.3470Hab (18)	+.1453Rain (+8%)	+.1295GrCov (+2%)	+.1255Cult (+3%),	+GrLand, –Open +FoWd

It is arguable that rainfall is the primary cause of the distribution patterns of the different vegetation types, and so is effectively a duplicate measure of the variability in vegetation category levels. Similarly, it could be argued that habitation density is a duplicate measure of cultivation. Accordingly, the analyses were repeated, once without rainfall, and again excluding both rainfall and habitation density (see Appendix Tables 5.1, 5.2).

In both sets of repeated analyses, cultivation remained the primary predictor of animal density, and grass cover added comparatively little to the statistical significance of the relationships identified.

This confirms the overriding importance of the levels of human activity as a predictor of livestock numbers.

Implications

Both bivariate and multivariate analyses suggest that livestock numbers are more closely associated with the consequences of human activity — either cultivation or habitation levels — than they are with any of the environmental characteristics available in the ERGO database. **In particular, the extent or distribution of natural grazing, either expressed as rangeland or as grass cover, is shown to be of limited relevance to livestock numbers.**

This pattern of relationships also holds true for pastorally managed livestock, and indeed the analyses suggest that for these animals, it is cultivation rather than habitation levels that is of primary significance.

The strength of the relationships, in statistical terms, is startling given the breadth of ecological conditions, geographical regions, and land-use type from which the data are drawn, and leaves very little room for doubt that the links are real and not a statistical artefact. Further, the similarity between the trends established for all livestock and pastorally managed livestock suggest that there is no reason to view the latter as a special case, affected by factors specific to the pastoralist management system.

This conflicts with many currently held views that assume pastoralist animals to be more tightly linked to natural vegetation than to human activity. Traditionally, pastoralists are supposed to move between areas of natural grazing as the seasons dictate, and to make use of the resources represented by permanent cultivation only at certain times of the year — generally towards the end of the dry season when there is not much natural grazing available.

This apparent discrepancy between theory and fact can be reconciled by several possible explanations, four of which are given below:

1 *The traditional theories are, and always have been, wrong.*

This is unlikely to be the case, not least because at some point in the past, human population and the attendant cultivation levels were substantially lower than they are at present, and thus were unlikely to be widespread enough to be a significant resource for livestock.

2 *The current results are wrong. Because the current analyses are concerned with annual mean livestock levels, and cover a wide range of ecological regions, they conceal the fact that pastoralism and natural grazing may be linked in some areas but not others.*

This idea is also difficult to support, given the statistical evidence. However, it is distinctly possible that an investigation of seasonal or species-specific factors may bring to light certain conditions or regions where the primary human/livestock links are over-shadowed by other factors.

3 *The traditional links were, at some time in the past, tenable, but are no longer operative.*

There is little doubt that livestock management systems have changed over the last two decades. There have been repeated and extensive droughts in the more arid regions covered by this study, and as a result, livestock ownership patterns have changed so that many previously nomadic pastoralists no longer own the stock they look after. Further, there is mounting, if circumstantial, evidence of increasing pasture degradation in the drier parts of the Sahel, either through overgrazing, or through the effects of an expansion of cultivation that is the inevitable consequence of increasing human populations. Thus it seems likely that the predictability of natural grazing as a resource has declined.

It is generally accepted that human populations have also expanded into previously unpopulated areas, particularly into the wetter areas, thereby clearing the natural vegetation for cultivation (see above). As a result, regions that were originally suitable for livestock only during the dry season, when, for example, the risk of trypanosomiasis was low, have been opened up to livestock in general, and cattle in particular, throughout the year. This has meant that animals that used to migrate in and out of the wetter areas on a seasonal basis, are now just as likely to remain permanently in the more southern locations, rather than move north, if only because the predictability of either natural grazing or cultivation is greater in the wetter areas than it is in the dryer ones. This has had the effect of relocating the centre of livestock distribution southwards, and so away from the arid rangelands in the north; a drift that may have been reinforced by the degradation of the natural dry-land grazing resources.

The southward relocation has had two consequences. First, there has been an increase in livestock populations within ecological zones that are less seasonally deficient in natural grazing than are the arid lands to the north. Second, there has been a reduction in the need for long-distance transhumance between wet and dry season grazing areas. Thus the traditional distinction between management systems used by pastoralists and agropastoralists have become increasingly blurred. Pastoralists are settling and growing crops, agropastoralists are acquiring livestock and sending them on transhumance, though generally for relatively short distances.

This trend has led to a closer involvement of stock owners with the cash economy, and thus an increase in the number of settled pastoralists — or, conversely, a decline in the number of pastoralists who are nomadic.

4 *The links between livestock and cultivation established by the current analyses are misleading, and there is an unknown factor related to cultivation that is the causal factor determining livestock distributions.*

Given that regression analyses can only identify associations and cannot be used to establish causal relationships, it is not possible to state with any certainty that it is cultivation *per se* that attracts livestock. It is possible, indeed likely, that where there is cultivation, there will also be patches of grazing or browse that are suitable for livestock. This is particularly true in areas which are extensively (as opposed to intensively) cultivated with large amounts of marginal fallow or recently cultivated land. Also, in areas where cultivation is limited to specific areas, such as Wadis, the presence of cropping and grass are likely to coincide.

It may therefore be the case that the livestock are not concentrating where the cultivation is, but rather where the edges of the cultivation are.

Whatever the correct explanation for the livestock/cultivation link (and it probably contains elements of all those suggested above), it seems very likely that extensive rangelands do not support large numbers of livestock, and that animals are concentrated in areas where cropping levels are highest.

Whether it is the actual cultivation, or the marginal resources associated with it that are the attraction is debatable and, in the current context, unresolvable. However, to some extent, this is irrelevant as far as the development implications are concerned. The fact is that animals are found in the largest numbers in or near human settlement, rather than in remote rangelands.

If human populations continue to increase, as they are almost certain to, and cultivation carries on expanding into areas so-far unpopulated, the livestock/cultivation interface can only become more important. It also seems likely that as levels of cultivation rise, it will increasingly come to represent the most predictable resource for livestock. In this way, the need for risk-aversion strategies, such as long-distance transhumance to seasonally available patches of natural grazing that are heavily and unreliably dependent on rainfall patterns, will be reduced.

Accordingly, it seems essential that future development planning should address this interaction as a priority. There are many topics of possible relevance in this context, some of which are already on many development agendas. The potential for conflict between pastoralists and arable farmers over, for example, crop trampling or disputed access to water sources, has received some attention. However, it seems likely that the changes in stock ownership patterns combined with recent clearance of natural vegetation may create additional barriers to pastoralist/farmer relations. Traditionally, pastoralists have negotiated access to crop residues in return for manure and milk, and these arrangements have persisted between clans from year to year. If many herds are no longer owned by the herders, then it is probable that the individuals managing the animals will change from year to year. If the arable farmer is only recently settled, then the possibility of maintaining permanent arrangements is reduced, and the potential for disagreement increased.

The concentration of animals in or around extensively cultivated areas may also contribute significantly to land degradation. Stock movement can trigger gully erosion, as can be seen on the Mambila highlands of Nigeria, and intensive grazing may compound the effects of over-cultivation in marginal areas.

It will be particularly interesting to establish the specific characteristics of cropped land that is attracting the animals: the lack of trypanosomiasis; the crops themselves; the ancillary grazing and browse available. If the last of these, could arable farmers be induced to manage their land to increase these feed resources more efficiently, in order to promote livestock production?

Such issues are obviously relevant to all areas that are cultivated, but are likely to be particularly important in regions where cultivation is limited to small patches: for example, the riverine *(fadama)* cropping common in the semi-arid regions; the Wadi and Khor or lakeside cropping in the very dry areas; or in irrigated cultivation. In all such systems, the areas of human activity are likely to act as oases, and any interaction between farmers and pastoralists will be intensified. This will especially be the case if the settled farmers themselves own animals, and their crops attract livestock from elsewhere.

If, as this analysis suggests, there is little distinction between the factors that are associated with pastoralist and village (i.e. farmers') livestock, then the question arises as to whether development planners should treat pastoralists as separate from farmers. In regions where livestock numbers are high, it seems probable that maintaining such distinctions will become increasingly unnecessary, as the undeniable trend appears to be away from pastoralism towards agropastoralism. Adhering to a distinction of decreasing relevance, either through a reluctance to abandon familiar concepts, or perhaps through a distrust of regional overviews, may result in substantial development resources being devoted to denying the inevitable. It would seem preferable to use the limited resources available to ameliorate the discomfort of those who are most affected by the changes that are taking place.

A cautionary note must be added to this discussion. It is easy to conclude from overviews such as this that pastoralism is no longer the significant force in livestock management that it once was. This may be the case to a degree. However, just because animal densities may be higher in cultivated areas, this is not to say that there are no livestock where there is no cultivation. The data presented above show that the mean livestock density in areas with no cultivation is about 3 TLU per square kilometre, equivalent to 3 camels, approximately 3 cattle or 30 small ruminants. Since much of the Sahel and sub-Sahelian Africa is uncultivated, this density represents very substantial numbers of livestock, and despite amounting to a relatively small fraction of the total (in the region of 10 per cent), must still be significant enough to warrant attention. These livestock also, of course, represent the livelihoods of large numbers of people.

Recommendations for further study

The present analyses have deliberately adopted the overview approach as the least complex way of exploring the data available. It is suggested that, if significant results emerge despite the diversity of areas and conditions covered, then the relationships contribute significantly to land degradation. Stock movement can trigger gully erosion, as can be seen on the Mambila highlands of Nigeria, and intensive grazing may compound the effects of over-cultivation in marginal areas.

It will be particularly interesting to establish the specific characteristics of cropped land that is attracting the animals: the lack of trypanosomiasis; the crops themselves; the ancillary grazing and browse available. If the last of these, could arable farmers be induced to manage their land to increase these feed resources more efficiently, in order to promote livestock production?

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Recommendations for further study

The present analyses have deliberately adopted the overview approach as the least complex way of exploring the data available. It is suggested that, if significant results emerge despite the diversity of areas and conditions covered, then the relationships must be strong enough to apply despite the variability that is bound to be a feature of the data collected.

This preliminary study must therefore be viewed as a first step. Having identified some significant trends, the analysis can then be extended to find out whether these same trends are equally significant within subsets of the information available. This could be done in several ways:

1 The overview approach could be continued, with additional information being incorporated into the data set. This additional information could either be from other areas for which comparable data are available, such as Senegal, Zimbabwe, Botswana or Kenya, where aerial surveys have been in use for some time, or it could describe additional environmental factors such as soil type, drainage, and altitude. It would also be possible to use economic or animal productivity data as variables, instead of animal biomass.

Another possibility would be to perform some kind of sensitivity analysis on the relationships identified at present. For example, one could look at the likely consequences of a 10 per cent increase in human populations on the numbers of livestock.

It should also be possible to identify regions that are particularly heavily stocked, and so at risk of being overexploited.

2 The relationships identified so far could be examined at a more local level, which could be either administrative or eco-climatic, to see if this gave a similar picture. For example, one could look at whether cultivation is as important to livestock in the humid zone as in the driest areas, or in Chad as well as Sudan; and it might be possible to see if there were conditions under which some other parameter were the best predictor of livestock distribution.

3 The influence of seasonality on the distribution of livestock and its association with predictor variables could be examined. This would be of particular interest as more of the available data could be incorporated into the analyses, specifically those from surveys where figures for a single season are available.

4 The factors associated with the distribution of the different livestock species could be investigated. For example, it is possible, indeed probable, that camels are not associated with the same environmental factors as small ruminants. Assessing the species composition of the livestock in different environmental and socio-economic conditions would be of considerable interest, and would allow planners to identify the conditions under which particular species predominate.

5 The present information could be used as a baseline for comparison with livestock data from earlier estimates. This would establish trends in population levels over time, or provide for an assessment of future trends if suitable data become available in due course. However, this avenue of study is likely to be the most problematic because of the difficulty of ensuring compatibility between estimates made by different techniques.

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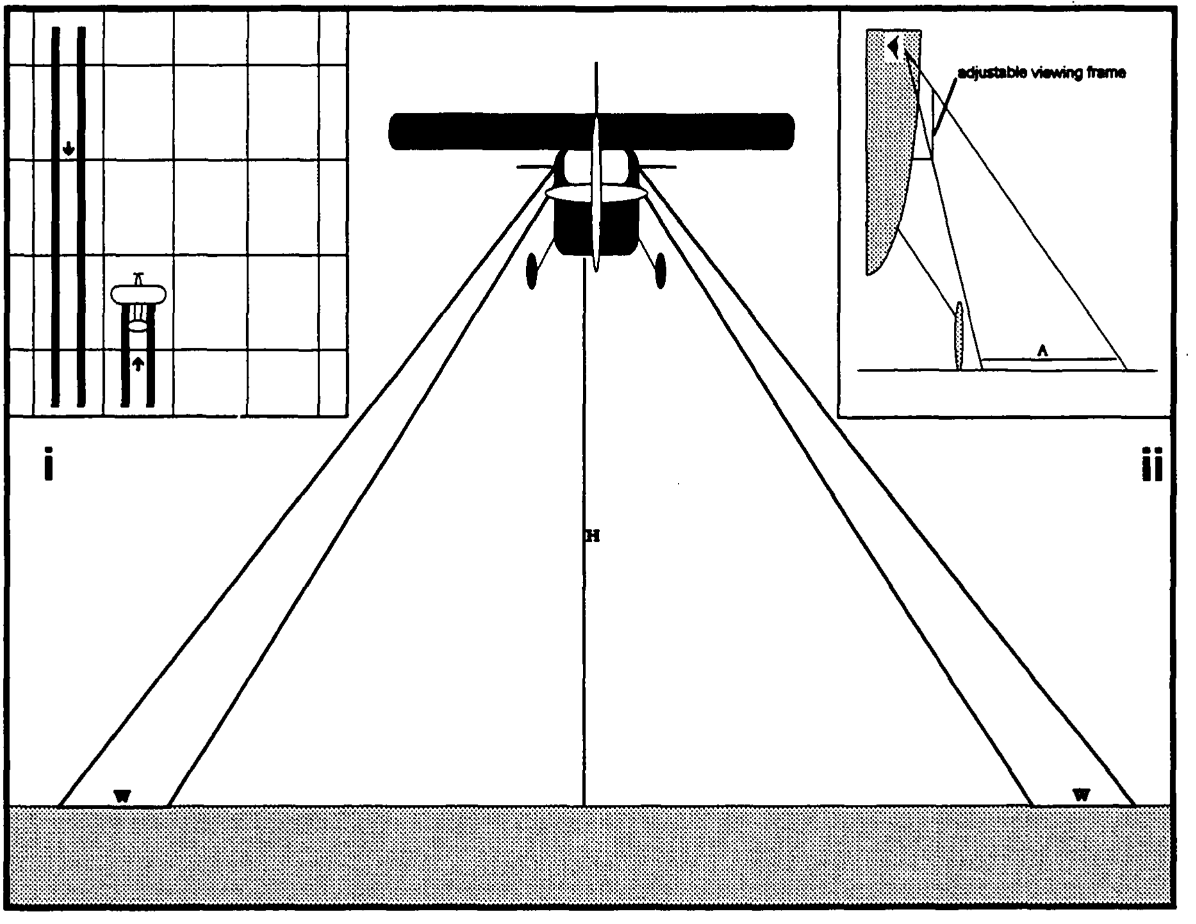
Appendix 1: Aerial survey sampling



The aircraft flies in parallel lines over the study area (i), and observers record from fixed sample bands to each side. The flight lines are divided into equal sectors, to create a grid cell lattice, by which each record is located. Only those herds and settlements which pass through the observation strips are counted and photographed. The strip width (W) is directly proportional to the flying height above ground (H) and is defined by externally mounted viewing frames (ii) which are adjusted to delineate a band on the ground (A) which corresponds to the desired sample band width W at the nominal flying height. Typically, W is 500m at 800 ft agl or 625m at 1,000ft agl. The air crew consists of a co-ordinator/navigator, pilot, and two observers or photographers.

Appendix 2: Summary of surveys carried out since 1980 and included within the ERGO data set

Country	Locality	Agency*	Date	Area	Grid	Livestock[1]	Habitation[2]		Vegetation
				Km²	Area	Past	Vill		Cover[3]
MALI	Delta	ILCA	10–80	34944	83	Ct,Sr,Cm			
	Delta	ILCA	03–81	34944	83	Ct,Sr,Cm			
	Delta	ILCA	06–82	34944	83	Ct,Sr,Cm			Ct,Gr,Ow
	Gourma	ILCA	03–83	81640	82.3	Cm,Ct,Sr			Gr
	Gourma	ILCA	08–84	81640	82.3	Cm,Ct,Sr	Pa,Vil		All
	Fifth Region	IBRD	07–87	102137	81.7	All	All	Pa,Vil	All
NIGER	NRL	USAID	09–82	81550	82.3	Cm,Ct,Sr,			
	NRL	USAID	09–85	81550	82.3	Cm,Ct,Sr	Pa,Vil	All	
SUDAN	Gezira	IBRD	02–86	50569	56.3	All	All	Pa, Vil	All
	Gezira	IBRD	03–86	37969	56.3	All	All	Pa, Vil	All
	Red Sea	OXFAM	03–89	119900	100	All	All	Pa, Vil	All
	Red Sea	OXFAM	09–89	119900	100	All	All	Pa, Vil	All
CHAD	Bahr El Ghazal	IBRD	08–91	59800	100	All	All	Pa, Vil	All
	ZOP	IBRD	03–93	147,600	400	All	All	Pa, Vil	All
NIGERIA	Gongola State	IBRD	07–83	43875	25	Ct,Sh,Cm	Gt	Pa, Vil	All
	Gongola State	IBRD	03–84	43875	25	Ct,Sh,Cm	Gt	Pa, Vil	All
	Anambra State	IBRD	05–89	17675	25	All	All	Pa, Vil	All
	Niger State	IBRD	05–89	59,600	25	All	All	Pa, Vil	All
	National	IBRD	03–90	923,000	400	All	All	Pa, Vil	All
	National	IBRD	09–90	923,000	400	All	All	Pa, Vil	All

[1] Cm = Camels; Ct = Cattle; Sr = Small Ruminants; Sh = Sheep; Gt = Goats; All = Includes Equines

[2] Pa = Pastoralist; Vil = Village

[3] Ct = Cultivation; Gr = Grassland/Grass Cover; Ow = Open Woodland;
All = Bare Ground, Grassland/Grass Cover; Scrub, Open and Dense Woodland; Forest.
* ILCA: International Livestock Centre for Africa.
IBRD: International Bank for Reconstruction and Development
USAID: United States Agency for International Development
ZOP: Zone d'Organisation Pastorale. NRL: Niger Rangelands Project

Appendix 3: Regression and correlation analyses — basic principles and a worked example

Graphical plots

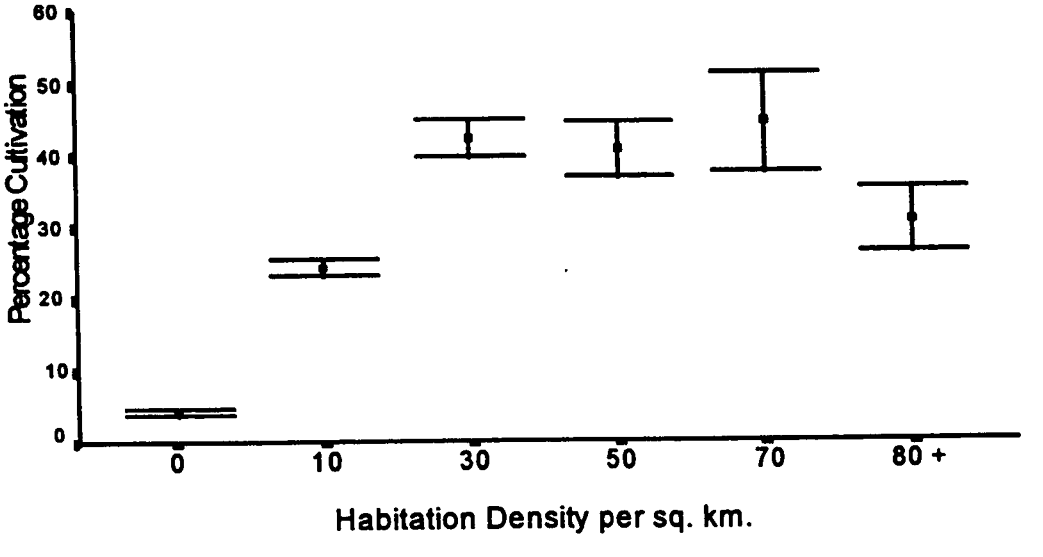
In each case, the data have been 'binned' or grouped into a number of categories, and plotted as means for each category, plus or minus two Standard Errors. This eliminates the confusion that a scatter plot of several thousand points would cause, and gives a preliminary indication of the variability of the livestock data within each category. The calculated regression lines, together with the proportion of variance explained, the sample size, and the statistical significance levels are shown at the bottom of each plot.

Linearised transformations of parameters included in the analyses

When the livestock biomass data are plotted against environmental or human settlement variables, the lines produced are not necessarily straight, but may be curved in various ways. As the multivariate analysis techniques assume linearity, incorporating some linear and some curvilinear relationships is likely to underestimate the relevance of the curvilinear associations. Thus, in order to assess the statistical relationships between the variables, these curves must first be straightened or 'linearised'.

To take a specific example, consider two parameters that are intuitively closely associated — habitation density and cultivation levels:

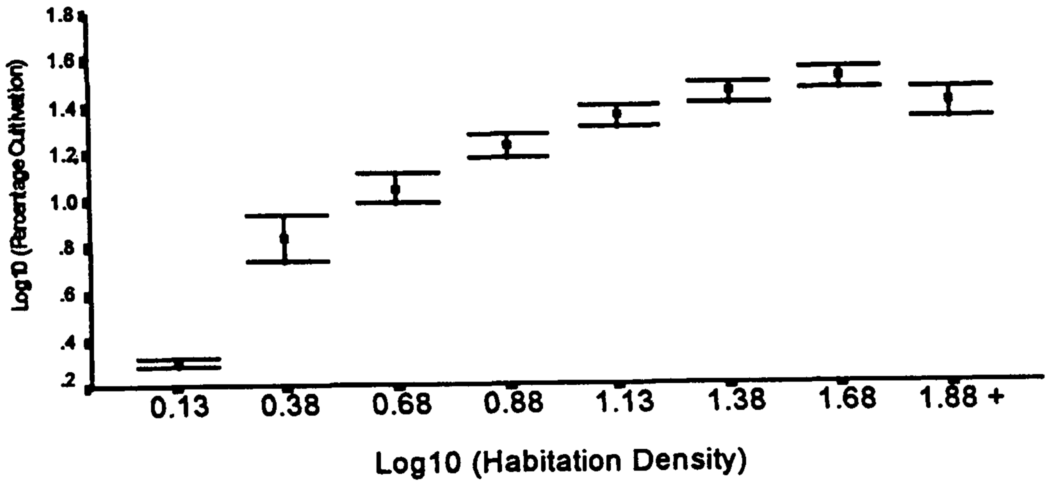
Figure 3.1: % cultivation: habitation density



The plot given above shows that cropping levels rise with habitation density, but in a non-linear fashion — cultivation intensity reaches a maximum in those areas where there are more than 30 habitations per square kilometre. There is some evidence that where habitation levels are highest, less land is cultivated — perhaps the cultivation in such areas tends to be more intensive, as opposed to extensive.

By converting both parameters to their logarithms, the line is straightened, and the statistical significance of the regression line fitted through the point is much increased:

Figure 3.2: % cultivation: habitation density — logged values



Log10 (% Cultivation) = 0.3683 + 0.7475 Log10 (Habitation Density). $R^2 = 0.478$; DF 2, 4402; $p << 0.0001$

Accordingly, all parameters except annual rainfall have been logged. Using the logarithm of annual rainfall did not improve the degree of linearity, because the basic relationship is in the form of an upside-down U. This can be straightened by an equation of the form $y = a + bx + c/x$. The constants a,b, and c were calculated using an iterative model provided by the statistical software package used.

Bivariate correlations

The bivariate correlations between the various parameters are shown in Table A2 below. The four independent (i.e. predictor) variables most closely related are indicated by the figures in brackets. The significance of each relationship is determined by the value of the correlation coefficient (R).

Table 3.1: Bivariate correlation coefficients
(Figures in brackets represent ranked order of correlation)

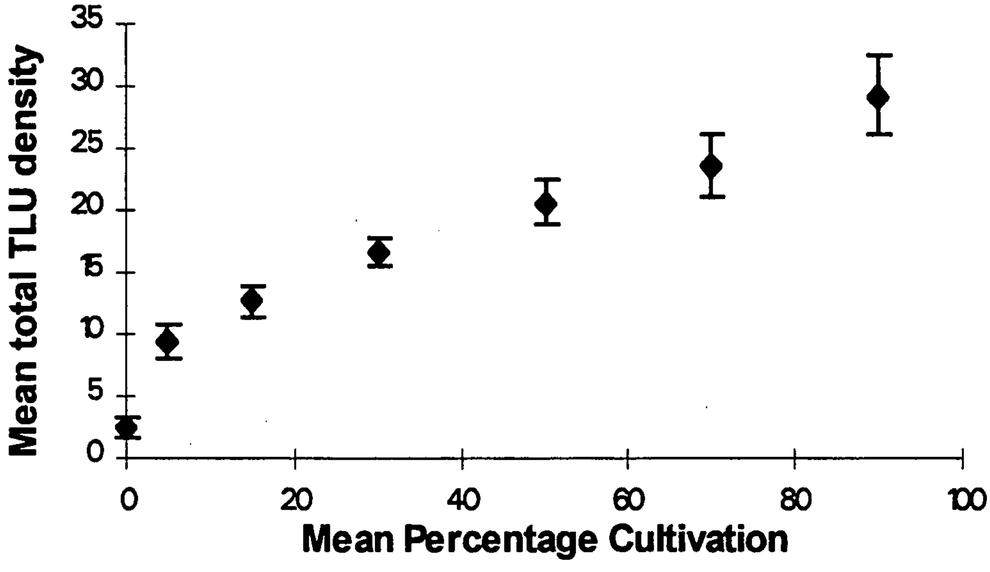
Independent Variable (x)		Total Biomass (Log TLU/km²)	Pastoral Biomass (Log TLU/km²)	Proportion of Biomass which is Pastoral (2)
% Cultivation	R	.7313 (1)	.5183 (1)	–.1875 (4)
(Log Annual Mean)	N	3633	4403	3353
	P <	0.000	0.000	0.000
% Rangeland	R	–.24 02	–.0153	.2308 (3)
(Log Annual Mean)	N	3273	4685	3042
	P <	0.000	0.296	0.000
% Grass Cover	R	.3202	.3197 (3)	.2105
(Log Annual Mean)	N	3273	4678	3042
	P <	0.000	0.000	0.000
Permanent Habitation	R	.7120 (2)	.2454 (4)	–.4718 (1)
(Log No/km²)	N	3633	5045	3353
	P <	0.000	0.000	0.000
Annual Rainfall (mm)	R	.3283	.0555	–.4033 (2)
	N	3633	5058	3353
	P <	0.000	0.000	0.000
Rainfall	R	.6067 (3)	.4364	–.0531
Linearised for Total Biomass	N	3633	5058	3353
	P <	0.000	0.000	0.002
Rainfall	R	.5770	.4615 (2)	.0859
Linearised for	N	3633	5058	3353
Pastoral Biomass				
	P <	0.000	0.000	0.000
% Forest & Woodland	R	.2171	.0455	–.0756
(Log)	N	3633	5065	3353
	P <	0.00 0	0.001	0.000
% Open Woodland	R	.1616	.0772	.0781
(Log)	N	3633	5065	3353
	P <	0.000	0.000	0.000
% Forest	R	.2171	. 0455	–.0756
(Log)	N	3633	5065	3353
	P <	0.000	0.001	0.000
% Dense Woodland	R	.4184 (4)	.1374	–.1424
(Log)	N	3633	5065	3353
	P <	0.000	0.000	0.000

It should be emphasised that nearly all the relationships are highly significant in statistical terms, largely because there are so many points — the threshold value of R at the 1 per cent level is 0.115, with only 1000 points. Theoretically, therefore, in all the relationships plotted, there is considerably less than a one in ten thousand chance that they are false.

In ecological terms, a more intuitively useful measure of significance is the proportion of variance in the dependent parameter explained by variation in the environmental one (R^2). In the view of the writers of the ERGO report, if this value exceeds 0.2 then the relationship is one that demands serious attention. A value of more than 0.33 suggests a very strong association between the two sets of figures.

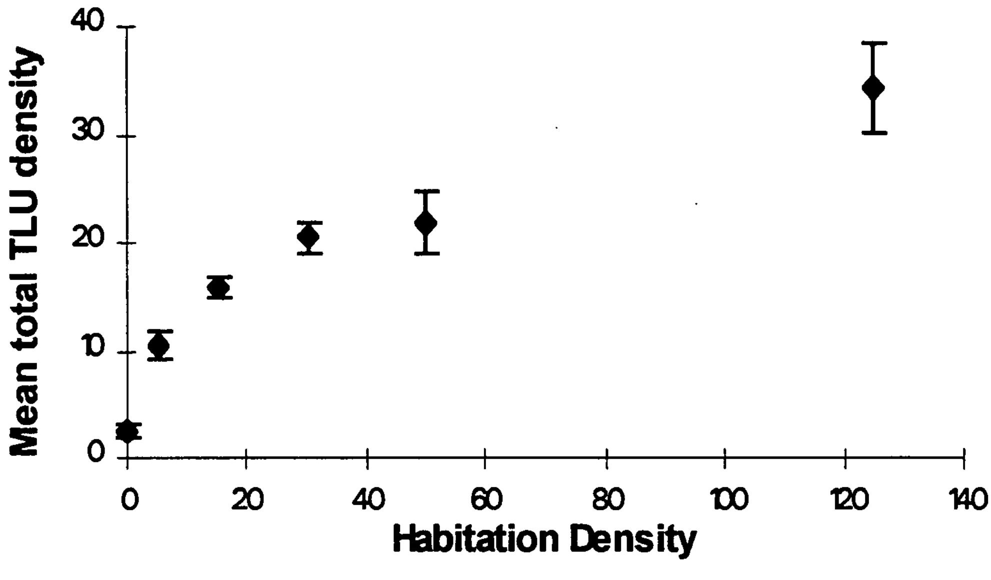
Appendix 4: Relationships found between livestock and the environment

Figure 4.1: Total livestock biomass: % cultivation



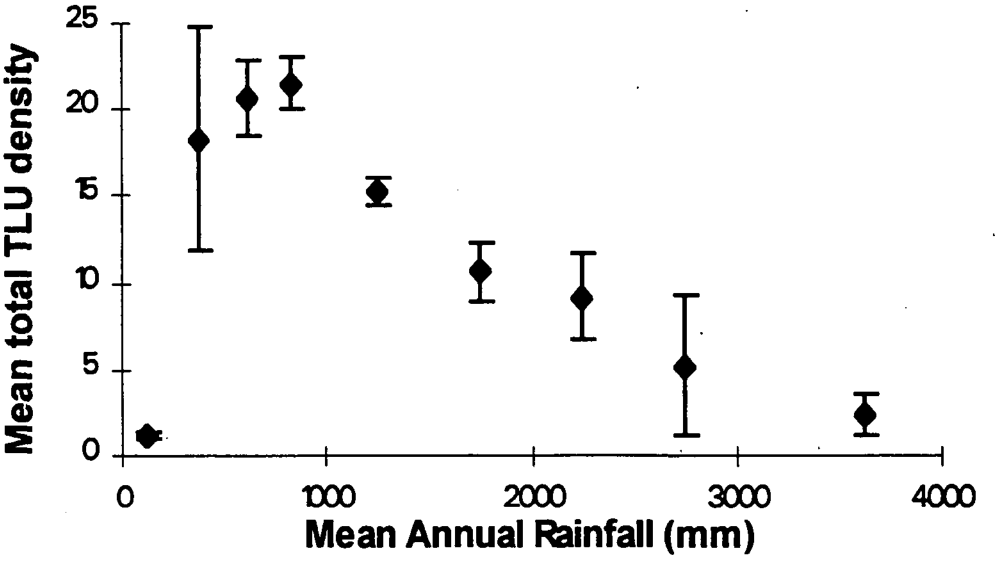
Log10 (Y)=0.3014 + 0.5561 Log10(X).R^2=0.535; N=3663; $p < 0.0001$

Figure 4.2: Total livestock biomass: habitation density



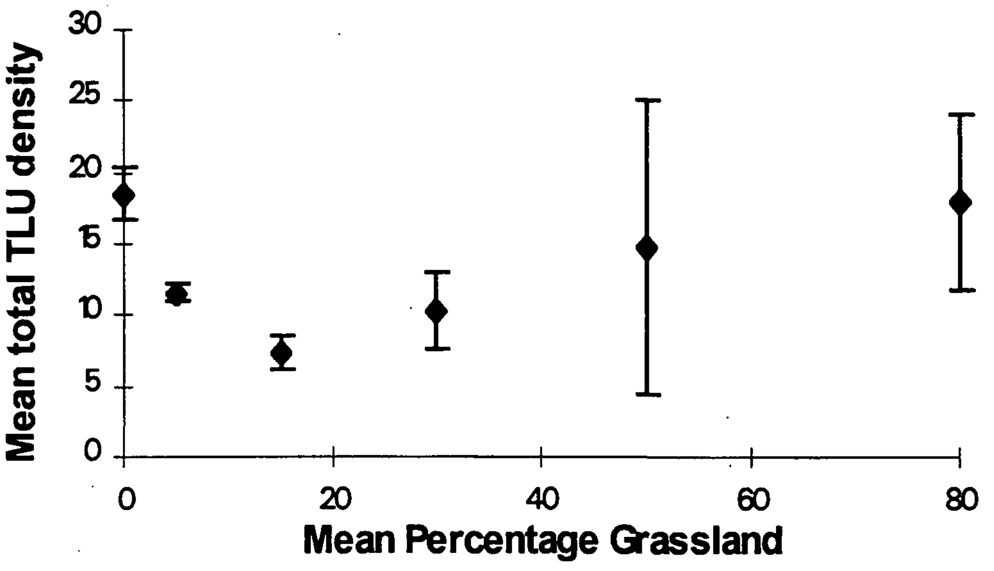
Log10 (Y)=0.3582 + 0.5897 Log10(X).R^2=0.507; N=3663; $p < 0.0001$

Figure 4.3: Total livestock biomass: rainfall



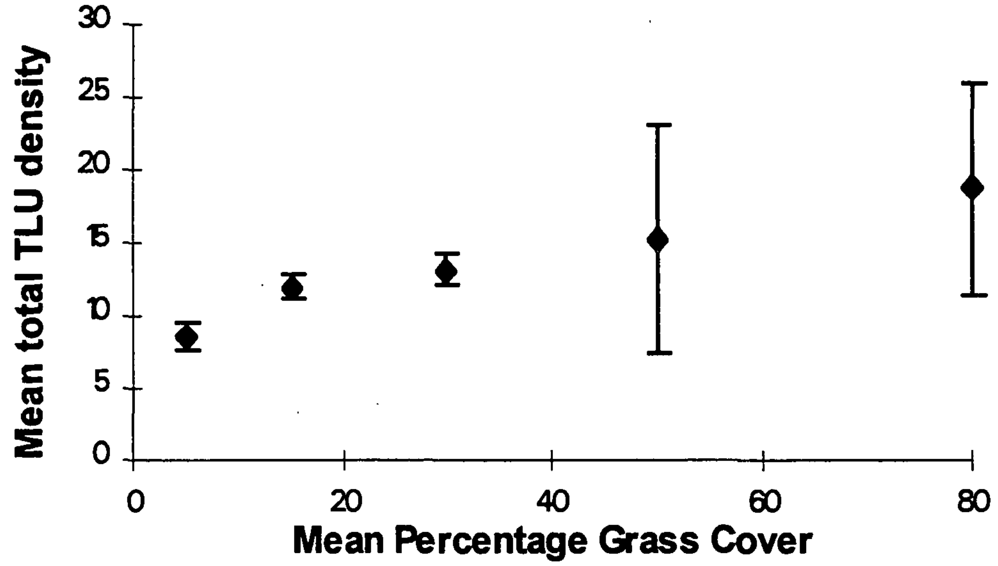
$\text{Log10}(y)=1.082 - 0.00007(x) - 50.59/(x)$. $R^2=0.3681$; N=3663; $p < 0.0000$

Figure 4.4: Total livestock biomass: % grassland



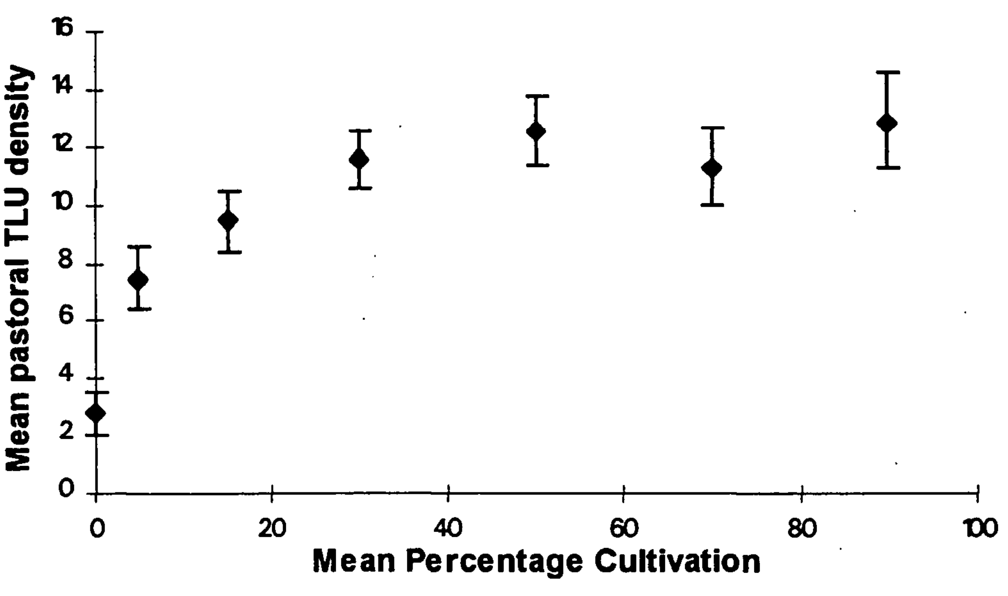
$\text{Log10}(Y)=0.9739 - 0.2745\ \text{Log10}(x)$. $R^2=0.057$; N=3273; $p < 0.0000$

Figure 4.5: Total livestock biomass: % grass cover



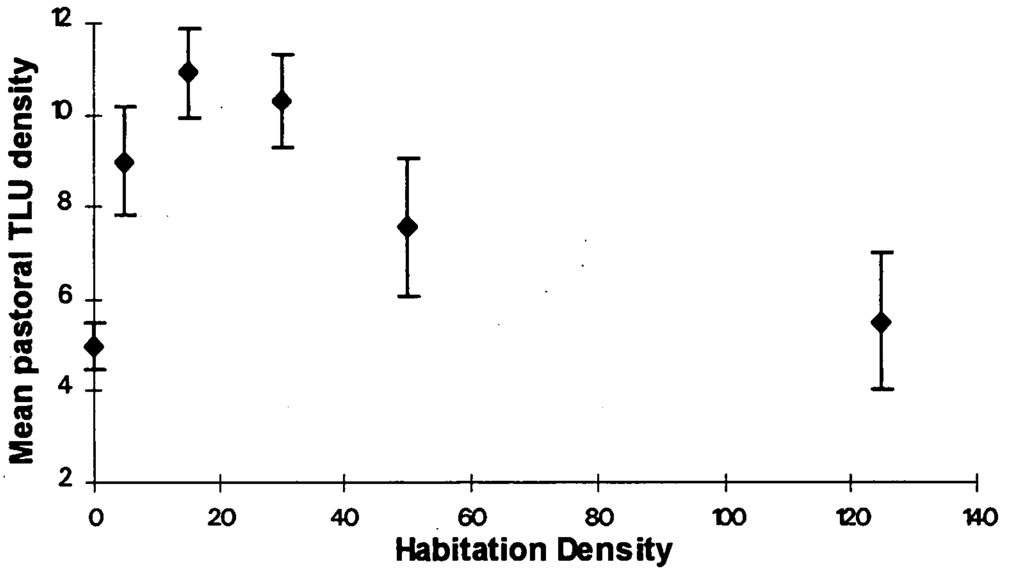
Log10 (Y)=0.3122 + 0.4267 Log10(x).R^2=0.103: N=3273; $p < 0.0000$

Figure 4.6: Pastoral livestock biomass: % cultivation



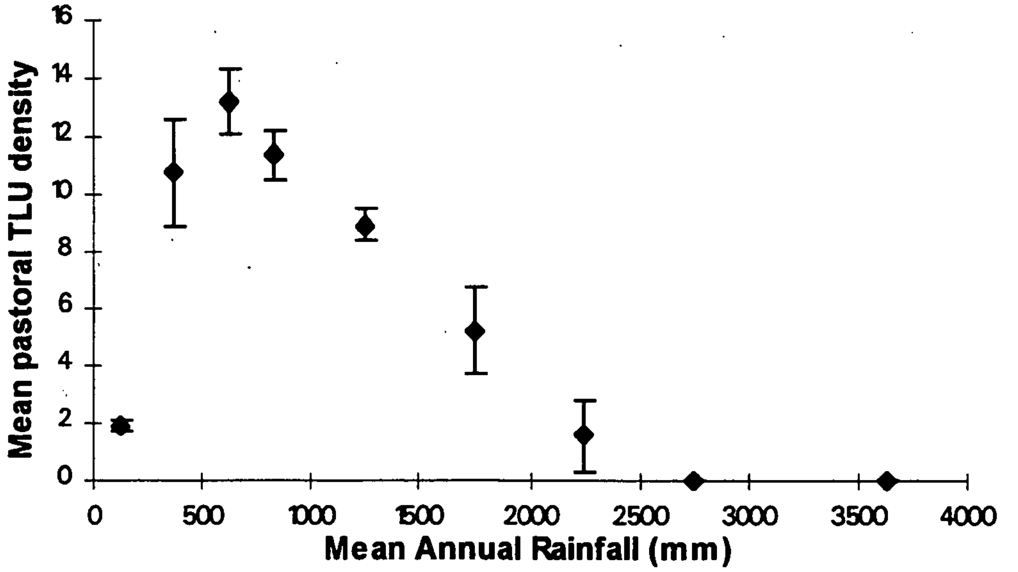
Log10 (Y)=0.3105 + 0.3777Log10(X). R^2=.269; N=4403; $p < 0.0000$

Figure 4.7: Pastoral livestock biomass: habitation density



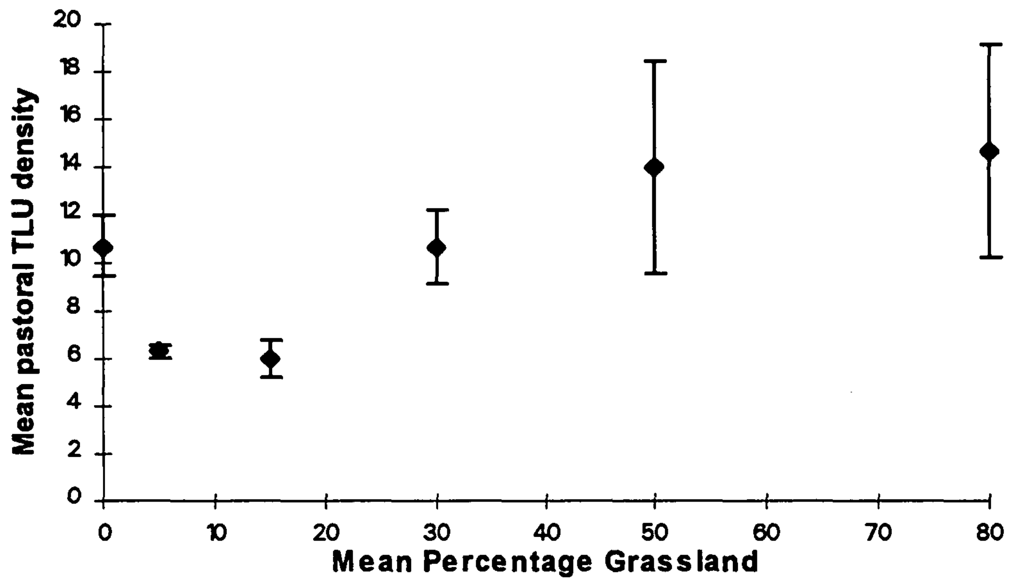
$Log10(Y)=0.4977 + 0.1940\ Log10(X)$. $R^2=0.060$; $N=5045$; $p < 0.0000$

Figure 4.8: Pastoral livestock biomass: annual rainfall



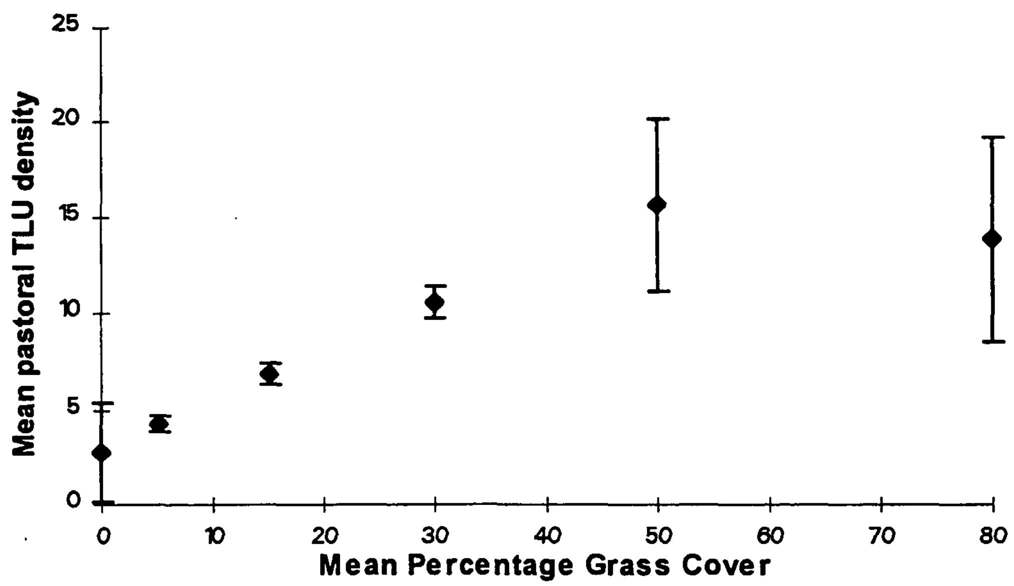
$Log10(Y)= 0.9246 - 0.0002(X) - 44.972/(X)$. $R^2=0.213$; $N=5058$; $p < 0.0000$

Figure 4.9: Pastoral livestock biomass: % grassland



No significant trend

Figure 4.10: Pastoral livestock biomass: % grass cover



Log10 (Y)=0.2883 + 0.3284 Log10(x). R^2=0.102; N=4685; P <0.000

Appendix 5: Stepwise multiple regression

Continuing with the example used in Appendix 3, this technique establishes the primary relationship between cultivation and habitation, and then assesses the correlation between cultivation and the next most closely correlated parameter (in this case linearised rainfall), whilst excluding the habitation/cropping interaction. At the next step, the method assesses the relationship between habitation and a third variable, in the absence of the interactions with the first two identified predictor parameters. At each step it calculates the proportion of the variation in cropping levels accounted for by the predictor variable being added to the analysis. If this proportion increases markedly between each step, then the importance of the added predictor is substantial. If the proportion increases little or not at all, then the added predictor variable's importance is similarly slight. This process continues until the addition of further predictor variables fails to increase the statistical validity of the equation generated.

The equation produced is given below, and shows that five environmental parameters are significantly related to cultivation, and that together they explain approximately two-thirds of the variation in cultivation levels. However, by far the strongest link is between cultivation and habitation density, which explains over half the variation. The addition of a second predictor variable adds six per cent to the R squared value, and the inclusion of extra predictors adds little to the predictive value of the equation.

Lg10 (% Cultivation) = 0.0348 + 0.6757Lg10(Habitation Density) + 0.2697 ('Rainfall') — 0.0592 Lg10(% Forest) — 0.1514 lg10(% Grass Land) + 0.0743 Lg10 (% Grass Cover).

R^2 =0.621, DF 6, 3626; p<<0.0001.

Step R^2: Cultivation (55); Rainfall (61); % Forest (62); %Grass Land (62); % Grass Cover (62)

From this, it can be stated with some assurance that habitation and rainfall are the two most important predictors of the levels of cultivation.

Livestock and environmental parameters — repeated multiple regressions

When rainfall is removed from the multiple regression analyses, habitation density or per cent cultivation remain the most important predictors of the density of livestock biomass:

Table 5.1: Multiple regressions of livestock and environmental variables, excluding rainfall

Dependent Variable	Best predictor	2nd Predictor	3rd Predictor	4th Predictor	Other Significant Correlates
Mean Total TLU R^2=.6947: DF=5,3267	+.3746Hab(60)	+.2924Cult(65)	+..2687GrCov(69)	–.0550Open(69)	+FoWd, –Dense
Mean Pastoral TLU R^2=0.4155: DF=4,4031	+.4181Cult (34)	+.1652GrCov(40)	+.1775GrLand (41)	+.0658GrCov(42)	
Proportion Pastoral R^2=..2998: DF=5,2547	–.3390Hab(18)	+.1796GrCov(25)	+.1439Cult(30)	–.0214Open (30)	+For

In the absence of habitation density, biomass density is still most closely linked to human activity (i.e. cultivation levels), but the proportion of animals which were pastoral becomes primarily associated with grass cover. This is, however, somewhat misleading as the overall predictive value of the resulting equations was very substantially lower than that of the analyses which included habitation levels, to the extent that 90 per cent of the variation in the proportions remained unexplained.

Table 5.2: Multiple regression of livestock and environmental variables, excluding rainfall and habitation

Dependent Variable	Best predictor	2nd Predictor	3rd Predictor	4th Predictor	Other Significant Correlates
Mean Total TLU R^2=..6357: DF 4, 3268	+.5455Cult(59)	+.2734GrCov (63)	–.04776 Open(63)	+.0530For(63)	
Mean Pastoral TLU R^2=0.4155: DF=4,4031	+.4181Cult (34)	+.1652GrCov(40)	+.1775GrLand (41)	+.0658GrCov(42)	
Proportion Pastoral R^2=.0981: DF=5,2547	+.1909GrCov(6)	–.0729Cult(7))	–.0339Open(9)	–.0175Dense (10)	+For